Accuracy Requirements

For potential users of location services, accuracy continues to be the most important consideration. However, radio signal location is a statistical process, and perfection is impossible to achieve. More sophisticated and more costly equipment and techniques can approach very high accuracy. Therefore, a company deciding on a location technology should balance its expectations and requirements with its willingness to buy.

For example, a long distance trucking company generally needs to narrow a truck's location to a certain region of a city. This can be achieved with existing technology simply by providing the truck's relative position to the nearest cell site (accurate to one mile to 20 miles).

Conversely, E-911 dispatch centers are establishing location accuracy goals of 40- to 400 feet so that assistance can be dispatched to a specific street corner or house. This can be achieved only by adding new location technology to wireless networks.

But even new technology is limited by the resolution of available maps. Most of the United States has been electronically mapped in a format known as the Topologically Integrated Geographic Encoding and Referencing system (TIGER), which was created for the U.S. Census bureau. Unfortunately, its accuracy is usually no better than 200 feet to 500 feet from true position. Many private firms are working to deliver more accurate maps, but these may not be available for all carriers and applications.

Location Update Rate

Location update rate, the speed with which new location information can be provided, also is an important consideration for a company buying location service technology. More rapid updates can use more channel capacity, resulting in more cost.

For example, given that a mobile unit emits two types of signals: control channel transmissions and voice channel transmissions — if location updates every few minutes are acceptable, then control channel transmissions provide an inexpensive and widely available signal that can be used for locating purposes. However, if continuous tracking is required, then the mobile unit's voice channel must be used. This requires a call to be continuously in progress during tracking.

Change to the Mobile Unit

Older wireless devices may need modifications so that location services can track them. For example, E-911 services need the capacity to locate all mobile users who dial "911" not just users of new, modified, or upgraded mobile units. Because it is cost prohibitive to upgrade or replace all mobile units, 911 services will require systems that will locate existing signals. Carriers can benefit from locating all mobile units so that they can bill calls at different rates based upon geographic location, and identify and prosecute those who use wireless services fraudulently.

Power Consumption in the Mobile Unit

As the size of mobile units continues to shrink, so does the space available for batteries. Therefore, power consumption becomes critical. Though users might find it intriguing to have a Global Position System (GPS) receiver inside their mobile units, they may find it cumbersome to carry the additional batteries such receivers require.

Where the Location Data is Stored

Customer requirements also determine where location data should be stored. For example, when the customer's primary need is to retrieve location information from the mobile unit, as with E-911 centers and billing by location systems, data should be stored in a central site.

But when the customer must use the location information at the mobile unit as with vehicle navigation systems, there may be no need to send data to a central location.

User Action Required for Obtaining Location Information

Human behavior factors must be considered before any technology is applied. What action will users have to take in order for location systems to work? At minimum, users may be asked to make sure their mobile units are turned on. But the actions required of the users can get more demanding. For example, a GPS receiver will not work inside a building, therefore a user is required to go outdoors in order for location information to be sent or received.

A system that uses the voice channel signal either for locating a mobile unit or for transmitting location information from the mobile unit to a central site requires that a call be placed and that a voice channel be available. Conversely, a system that can locate a mobile unit's control channel permits location at any time without requiring a voice channel call, and without requiring the user to push any button on the unit.

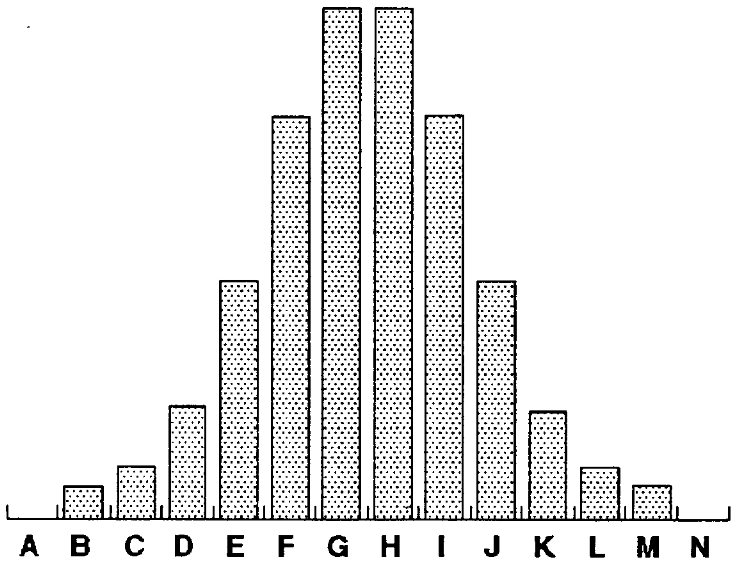
Technology Considerations

Once needs and requirements are understood, choices can be made from the variety of technologies currently in development. But there is one caveat that pervades all choices: No location technology can locate all wireless devices all of the time with very high accuracy.

All radio communications systems, by their very nature, are susceptible to impairments. For example, radio station reception or over-the-air television broadcast reception works well in some areas and in other areas reception may be plagued with static or shadows. Before cable reached most households, "ghost images" created by blowing tree branches danced across television screens. And, any avid cellular telephone user has noted that signal strength and clarity can vary by location.

A wireless communication system is affected by natural and man-made structures, including foliage, mountains, buildings, and even vehicles, as well as by the weather. These environmental features cause signal loss (i.e. attenuation), reflection and even partial or complete obstruction. These effects on radio communications can be shown in statistical representations that also apply to location technology.

Most statistical effects on location of radio transmitters have a familiar Normal or Gaussian Distribution as shown below:



In this Gaussian Distribution, the horizontal axis represents accuracy of the location estimate (for example, using one technology, B might equal 100 feet, G = 300 feet, and M = 500 feet). The vertical axis represents percentage of transmissions that can be located at the accuracy specified on the horizontal axis. The sum of all black bars always equals 100 percent.[6] For example, at letter "G", representing 300 feet, the percentage of transmissions that could be located at a 300-foot accuracy, might be 20 percent. The cumulative percentage for all accuracy levels A through G might be 50 percent. For this technology, then, one could say that one-half of all transmissions might be located with an accuracy of 300 feet or better.

For any technology, however, there will always be some small number of transmissions that cannot be located. For example, even if N equals one mile (5280 feet) in the chart, the cumulative percentages (A through N) might still be only 99 percent. Therefore, one could say that one percent of all transmissions could not be located to better than one mile. With the statistical nature of location technology in mind, the specific advantages and disadvantages of the five major technical approaches are described below.

Approach 1 - New Receiver In Cellular Phone

There are several signals available for location purposes in most areas of the country. These include Loran and GPS signals, and even FM radio signals. Of these, GPS is considered to be the most accurate (to about 100 feet), even with selective availability activated.

GPS signals are transmitted by orbiting satellites, therefore, there is the major drawback of weak levels of signals at the surface of the earth. These weak signals cannot penetrate buildings, and sometimes not even trees. Thus a user cannot expect to obtain location information while under any natural or artificial structure. Moreover, because the satellites spend a fair amount of their time between the horizon and directly overhead, tall urban buildings may also block the signal even when the receiver is outdoors.

The integration of GPS and wireless devices will undoubtedly occur, but the integration will be faced with several challenges. Traditional GPS antennae have been flat or helical in design because the devices are looking upward to the satellites for signals. Traditional mobile units have whip antennae because the base stations, or cell sites, are terrestrial and the signals are arriving from a horizontal direction. These different antenna objectives can be rationalized, but only at a higher cost.

Adding a GPS receiver to a mobile unit will create an additional power consumption load on the mobile unit's battery. This load may be greater than the power consumption of the mobile unit itself. Additionally, adding components of any kind to mobile units runs counter to the current trend of shrinking the size of these devices.

GPS receivers can provide continuous position updates, but only when they are able to transmit to and from satellites. If a mobile unit with embedded GPS receiver has been turned off or stored in a briefcase or purse, or is packed in luggage sent to a new city, the GPS receiver will generally require up to ten minutes to re-acquire the signal from a satellite.

Integrating GPS receivers and mobile units for use in location systems also will require significant cooperation among many organizations. A GPS receiver in a mobile unit is ideal when location information is needed by the mobile user. However, if the location information is required elsewhere, such as an E-911 dispatch center, the information must be sent over the mobile unit's voice or packet data channel. Implementing such a system across the U.S. would require competing vendors to work toward establishing a standard, creating interoperability procedures and tests, and then deploying the protocol support nationally.

GPS also can be ideal for many applications involving vehicles traveling on highways away from urban environments. For example, Intelligent Vehicle Highway Systems (IVHS) can take advantage of continuous updates, superior positional accuracy, and relative freedom from obstruction. Also, vehicle-based map applications that provide navigational directions can greatly benefit from GPS technology. GPS, however, may be less suited to a national E-911 deployment, where policy requires uniform support to all callers.

Approach 2 - New Transmitter In Cellular Phone

Signals that are designed for location purposes, such as GPS or the 902-928 MHz[7] technologies, generally employ a wide bandwidth (i.e. greater than one MHz) with specifically designed modulation structures. Signals of this type exhibit greater ability to resolve noise impairments and multipath reflections from natural and man-made structures. This is in contrast to existing analog mobile units which use narrow band channels (i.e. 30 KHz) that were designed for carrying voice conversations.

Several proposals exist today that call for overlaying new wideband signals on the voice channel transmissions. They involve adding new transmitting circuitry to mobile units and then integrating the wideband transmissions with voice transmissions for which the communications band was designed. This approach claims to gain for mobile units the ability to achieve GPS-like location performance without the drawbacks of a separate antenna design or the limitations imposed by satellite line-of-sight requirements.

Because this approach requires the design of a new signal, competing proposals would have to be harmonized into a standard, and interoperability procedures and tests would have to be created before any products could be introduced. The resulting standard must not create unacceptable interference (i.e. noise to a voice channel or data transmission). This requirement may limit the number of simultaneous location transmissions being performed in a given system or geographic area. Digital voice transmissions may be even more susceptible to interference than existing analog voice transmissions.

There are other drawbacks to putting new receivers in mobile units, specifically, increased power consumption requirements, additional transmitting circuitry and difficulty in providing uniform implementation for E-911 dispatch centers.

But countering the drawbacks may be several key advantages. In this technique, mobile location is calculated by the wireless system, and therefore no forwarding protocol is required. Additionally, there is no requirement that the mobile unit engage a voice or data channel.

Putting new receivers in mobile units may be appropriate for consideration in some future generation of PCS technologies. With the ability to design new signal structures, new mobile circuitry, and new infrastructure, anything is possible. But it is not suitable for use with currently deployed cellular technology.

Approach 3 - Measuring Power Level

The principle of power attenuation makes it possible to estimate mobile unit location using existing signals. When a signal is transmitted from an antenna, power radiates in all directions. An analogous activity occurs when a pebble is dropped into a calm pool, causing a circular ripple to radiate out from the pebble's entry point into the water. As the ripple or the signal travels outward, the signal level decreases, or attenuates, as distance from the antenna (the pebble's entry point) increases (similarly, the height of the ripple decreases with distance). This gradual decrease in power is well understood and embodied in various fundamental equations that make it possible to identify location by measuring power level. In this locating technique, the equations are used to estimate mobile device location by measuring the power of a received signal, querying to discover the power level at the time of transmission, and then applying other equations to estimate distance. The technique works whether the mobile unit measures cell site transmissions, or the cell sites measure mobile transmissions.

However, the technique is generally considered the least reliable method for estimating location for several reasons. Discovering transmitted power is a significant burden that is complicated by cell site sectoring, antennae down-tilting, and continuous wireless system tuning. Signals can attenuate for reasons other than distance traveled, such as passing through walls, foliage, or glass and metal vehicles. Signals can also be affected by variations in weather, changes in foliage, and other environmental factors. In addition, power measuring circuits generally cannot discern whether the power received is direct path or reflections off buildings, trucks or planes. This phenomenon is witnessed by any cellular user who has seen the "bars" on a telephone display fluctuate even when the mobile unit isn't moving.

Approach 4 - Measure Angle Of Arrival

Another technique that uses existing mobile device signals to estimate location is known as "angle of arrival" or "direction finding." Angle of arrival has been well developed among military and government organizations since it operates with no modification to mobile devices. The technique requires a complex antenna array — an arrangement of several antennae in a precise, fixed pattern — at cell site locations. Antenna arrays, in principle, work together to determine the angle (relative to the cell site) from which a mobile signal originated. When angles of arrival are computed for several cell sites, the mobile unit's location can be estimated based on the point of intersection of projected lines drawn out from the cell sites at the angle from which the signal originated.

An angle of arrival system can perform well when tracking a continuous transmission, such as a voice transmission. The system must follow each voice channel assignment as a caller moves from cell to cell, and the call is handed off from channel to channel. This can be difficult if the angle of arrival antennae are not positioned to interpret the in-band voice channel signaling. It is more difficult to use angle of arrival to compute the location of a mobile unit emitting brief (one-tenth of one second) reverse control transmissions. It may also be difficult to use angle of arrival based on digital voice channel transmissions and data transmissions because of the brevity of the signals and the channel sharing that exists.

Another significant drawback to angle of arrival systems is the logistical and aesthetic dilemma of adding antenna arrays (that can number from four to 12, depending on the angular resolution required) to cell sites at a time when communities are enacting increasingly harsh zoning regulations.

Also the accuracy of angle of arrival systems is reduced as a mobile unit moves away from a cell site. To illustrate this problem, think of cutting a triangular pizza slice. The transmitter is moving away from the tip of the slice. As it moves farther away, the ambiguity (or width) of the pizza slice becomes greater even though the angle of the cut remains constant.

Angle of arrival also is extremely sensitive to wide angle reflections (known as multipath reflections) that occur when a mobile device's transmissions reflect off natural and man-made structures, particularly buildings and mountains. These reflections can have power stronger than the direct path taken by the signal from the mobile unit to the antenna array. These multipath reflections can "trick" an antenna array into calculating an incorrect angle. For this reason, continuous reverse voice channel transmissions are more desirable than brief reverse control channel transmissions for angle of arrival systems because continuous reverse voice transmissions give angle of arrival systems time to attempt to resolve ambiguities due to multipath reflections.

Angle of arrival technology may lend itself to the future use of "smart antennae," which are compact antenna arrays that shape the cell site transmitter and receiver signals into a beam that focuses on the mobile unit and ignores other signals. Although potentially expensive, these antennae could improve call quality.

Approach 5 - Measuring Time Difference Of Arrival

Time difference of arrival is another well known technique used for determining the locations of mobile devices. Time difference of arrival has been used since radar systems were first invented over 50 years ago and is used with GPS technology today. It is well suited to estimating location of all wireless devices because it works with both brief transmissions, such as the reverse control channel, and with longer transmissions, such as the reverse voice channel. These systems work on the basis of a highly precise timing of a mobile unit's signal as the transmission is received at various cell sites. From the precise timing, appropriate triangulation can be performed to estimate position, as well as speed and direction of travel. In contrast to angle of arrival systems, the distance from the transmitter to any cell site is not a factor in accurate timing, and therefore does not degrade accuracy. Also, in contrast to both measured power and angle of arrival systems, time difference of arrival systems do not require that the signal be received at any appreciable power level (i.e. relative to the background noise level in the wireless band).

For many applications, time difference of arrival offers many positive benefits. The system requires no modifications to existing mobile devices, regardless of modulation protocol. Thus all of the existing 22 million[8] analog cellular telephones could be supported. As with other locating techniques, time difference of arrival systems typically require the addition of new equipment at cell sites though existing antennae can be used in many cases. Where existing antennae are not available, simple whip antennae (i.e. the type of cellular antennae on most car windows) can be used.

Because antenna requirements are simple and unobtrusive, time difference of arrival receivers can be put in many locations, including areas without cell sites. This might be advantageous if one wanted to improve location estimates in a particular area and a regular cell site was not required or desired. This simpler configuration has the added benefit of lower implementation cost compared to angle of arrival systems.

Though time difference of arrival systems are also affected by the same multipath reflections that impair angle of arrival systems, they are affected to a lesser degree because of the superior timing resolution and frequency resolution characteristics of the technique. It is generally considered easier to measure time precisely than to measure angle precisely.

The lower implementation cost of time difference of arrival systems permits receiver installation at more cell sites, which leads to a statistical averaging of the multipath reflections,[9] especially required in urban environments where there is a greater density of man-made structures.

Like angle of arrival, time difference of arrival systems are best suited for applications requiring the location information at a central site. Unmodified mobile devices are currently not capable of displaying position, but the central site can forward the information to a data receiver.

This wide range of available technology choices each offers at least one technical fit for each desired application whether it be for an E-911 system, Billing by Location, fraud detection and prosecution, System Planning and Design or the hundreds of new applications that will become available in the next decade.

Public Policy Considerations

Public policy discussion has followed every major technological development over the last century. The roll out of location systems will similarly require discussion and agreement on several principles. During 1994, the two Joint Expert Meetings and the FCC Notice of Proposed Rulemaking raised appropriate questions concerning:

- Liability
- Availability to all users
- Public funding for E-911
- Maintaining privacy

Liability is the first area of concern for every location system vendor. Because of the statistical nature of location technologies, there will be some mobile unit transmissions that cannot be located at any particular time. Vendors, wireless carriers, and E-911 dispatch centers will implement systems in a best effort to locate all callers, but some level of indemnification is needed if a mobile unit transmission is not located during an emergency. Fortunately, liability precedent for emergency services already exists.

Location service may soon be classified with E-911 service as an essential service that must be available to all callers on a non-discriminatory basis. As the proportion of wireless devices relative to landline telephones increases, locating wireless transmissions will be as critical as maintaining the databases that match landline telephone numbers with an address.

Wireless carriers will probably request public funding to implement location systems for E-911 purposes. Precedent exists for surcharges on both landline and cellular bills to pay for county and state E-911 systems. Location systems are an improvement to the level of service, and parity may dictate some similar approach to funding.

Finally, while most users will welcome the benefits of location services, there will also be some concerns regarding the protection of individual privacy rights. Carriers may be required to treat location information with no less sensitivity than billing, credit, or other personal data, including Automatic Number Identification (ANI) display. There are existing government policies covering the protection of tax, financial, medical, and credit records that have enabled both private and public sector organizations to collect, manage, and use the information appropriately.

Conclusions

There is no longer a question of whether location services will exist for wireless users; there are now only choices: Which applications and technology are best, and when will they be deployed. Location service systems will be welcomed for the public safety benefit they bring, and the new revenue sources and cost reductions they offer wireless carriers. As with all revolutions, it is difficult to predict the outcome ten years from now. If the last decade in wireless communication is any indication, however, set your expectations high.

[1]Estimates on a per-city basis have ranged from 15 to 40 percent, with the national average at 25 percent. In volume, 911 calls from mobile phones represent almost 7 million calls per year.

[2]See Notice of Proposed Rulemaking in FCC Docket No. 94-102

[3]The average household in the U.S. uses more than 1,000 minutes of voice traffic per month, inbound and outbound. Cordless phones are likely used for a significant portion of that calling. By contrast, cellular telephones carry a little more than 100 minutes per month.

[4] Cloning involves the illegal copying of the identifying numbers from one phone into another phone, and then misuse of the new phone.

[5] "Paging" is the process of notifying a cellular telephone of an incoming call, not the traditional transmissions to paging receivers.

[6] To reach 100%, all bars must be summed, including A, N, and many bars above N that are not shown.

[7] This frequency band has been set aside by the FCC specifically for Automatic Vehicle Location (AVL) systems, among other applications, but its use for AVL is currently uncertain pending a decision in FCC Docket No. 93-61.

[8] Estimate for 10/31/94 extrapolated based upon CTIA June 30, 1994 and December 31, 1993 surveys.

[9] Multipath reflections are highly dependent on the angles and positions of the buildings situated along the path from the mobile unit to the cell site. Since cell sites are widely dispersed, each path is different, and therefore the reflections experienced will be different and will average out statistically.

EXHIBIT 2

US005327144A

United States Patent [19]

Stilp et al.

[11] **Patent Number: 5,327,144**

[45] **Date of Patent: Jul. 5, 1994**

[54] CELLULAR TELEPHONE LOCATION SYSTEM

[75] Inventors: **Louis A. Stilp**, Broomall, Pa.; **Curtis A. Knight**, Washington, D.C.; **John C. Webber**, Herndon, Va.

[73] Assignee: **Associated RT, Inc.**, Pittsburgh, Pa.

[21] Appl. No.: **59,248**

[22] Filed: **May 7, 1993**

[51] **Int. Cl.**^{5} **G01S 1/24; G01S 3/02; H04M 11/00**

[52] **U.S. Cl.** **342/387; 342/457; 379/58**

[58] **Field of Search** 342/387, 457, 35; 379/58, 59, 60, 62; 364/449

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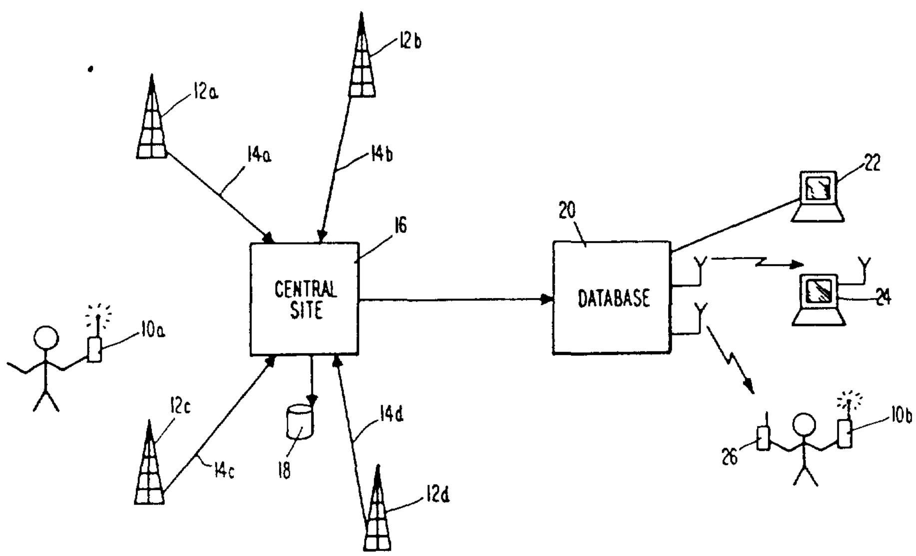
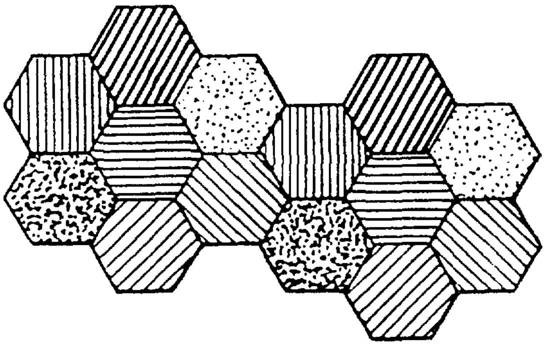
Primary Examiner—Gregory C. Issing
Attorney, Agent, or Firm—Woodcock Washburn Kurtz Mackiewicz & Norris

[57] **ABSTRACT**

A cellular telephone location system for automatically recording the location of one or more mobile cellular telephones comprises three or more cell site systems **12.** Each cell site system is located at a cell site of a cellular telephone system. Each cell site system includes an antenna that may be mounted on the same tower or building as the antenna employed by the cellular telephone system and equipment that may be housed in the equipment enclosure of the corresponding cell site. The cell site systems are coupled via T1 communication links **14** to a central site **16.** The central site may be collocated with the cellular telephone system's MTSO. The central site **16** is further coupled to a database **20,** which may be remotely located from the central site and made available to subscribers.

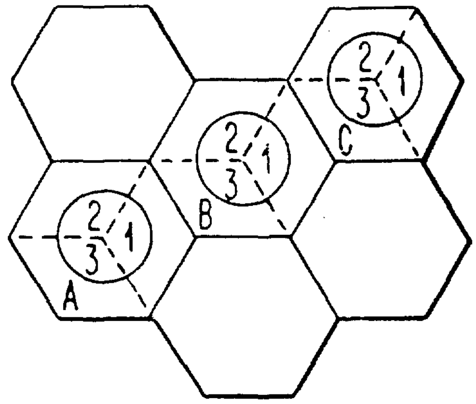
45 Claims, 15 Drawing Sheets





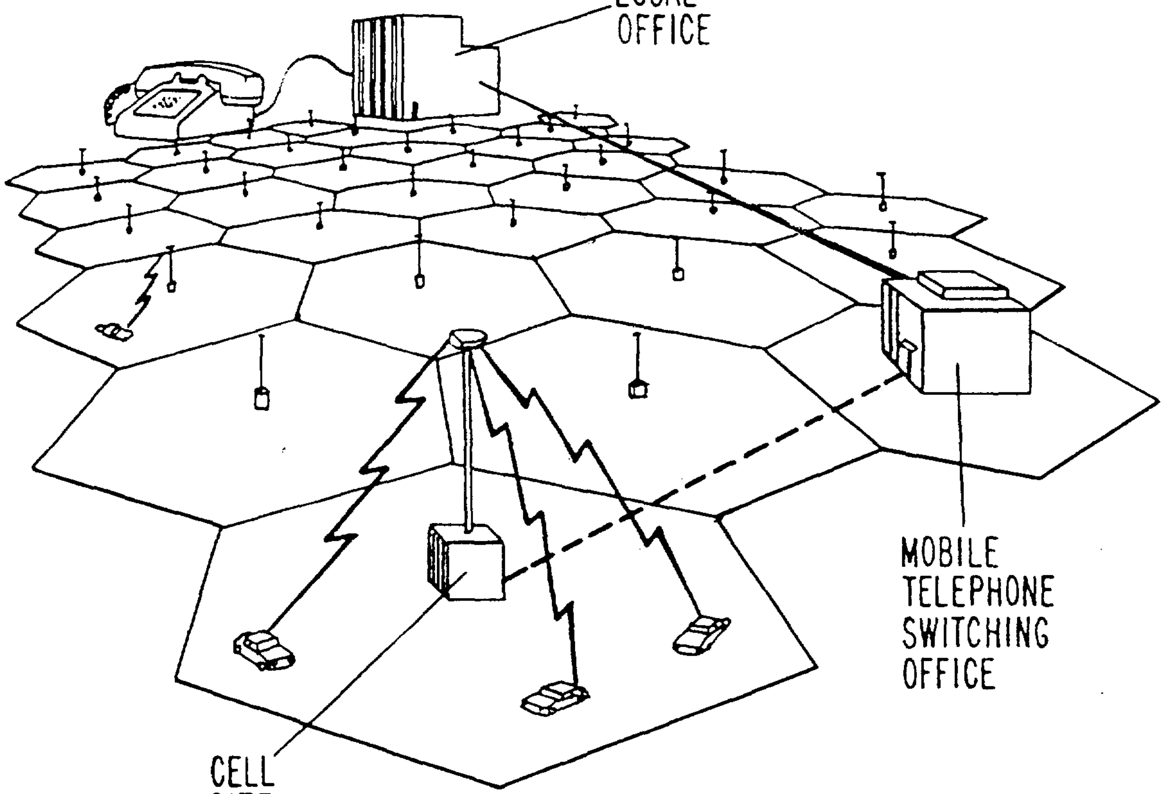
PRIOR ART

Fig. 1A



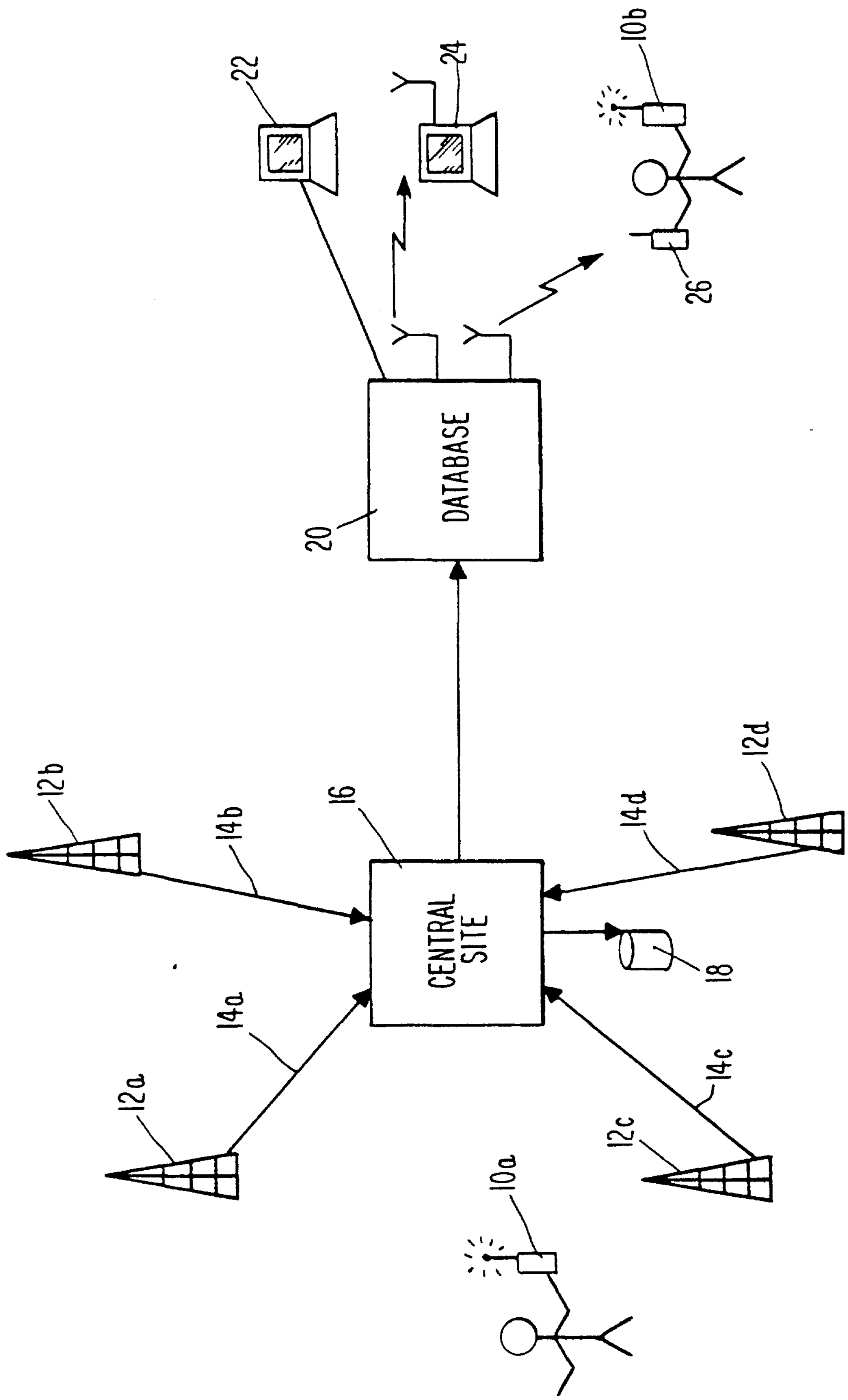
PRIOR ART

Fig. 1B



PRIOR ART

Fig. 1C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10b
26
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CENTRAL SITE
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12b
12c
12d
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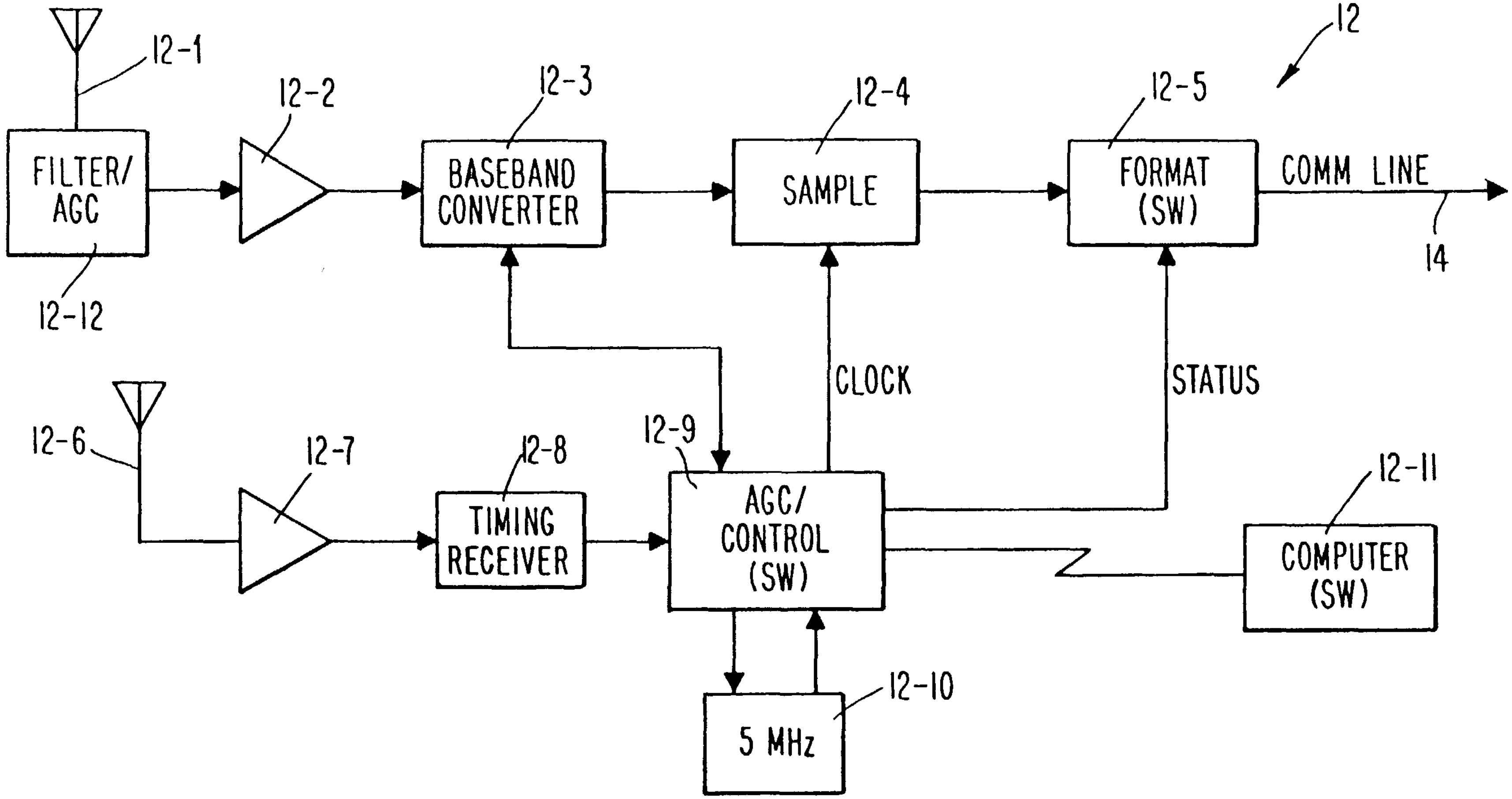
14b
14c
14d
10a

Fig. 2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12-2
12-3
12-4
12-5
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BASEBAND CONVERTER
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FORMAT (SW)
COMM LINE
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12-12
CLOCK
STATUS
12-6
12-7
12-8
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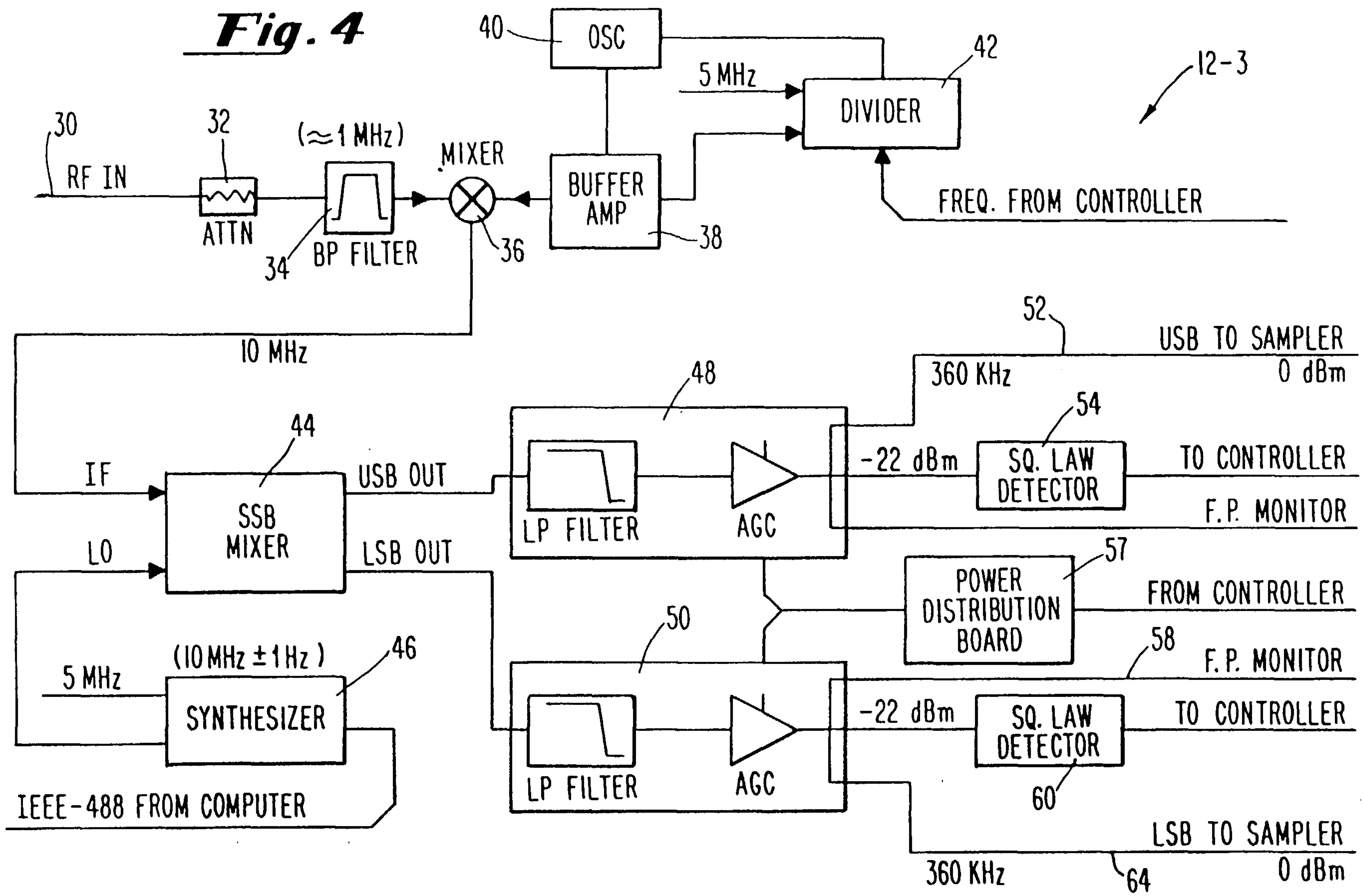
TIMING RECEIVER
AGC/ CONTROL (SW)
12-11
COMPUTER (SW)
5 MHz
12-10

Fig. 3

Fig. 4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OSC
5 MHz
42
DIVIDER
30
RF IN
32
ATTN
(≈1 MHz)
MIXER
BP FILTER
34
36
BUFFER AMP
38
FREQ. FROM CONTROLLER
10 MHz
52
USB TO SAMPLER
360 KHz
0 dBm
48
54
44
IF
SSB MIXER
USB OUT
LP FILTER
AGC
-22 dBm
SQ. LAW DETECTOR
TO CONTROLLER
F.P. MONITOR
LO
LSB OUT
57
POWER DISTRIBUTION BOARD
FROM CONTROLLER
50
(10 MHz ±1 Hz)
46
5 MHz
SYNTHESIZER
58
F.P. MONITOR
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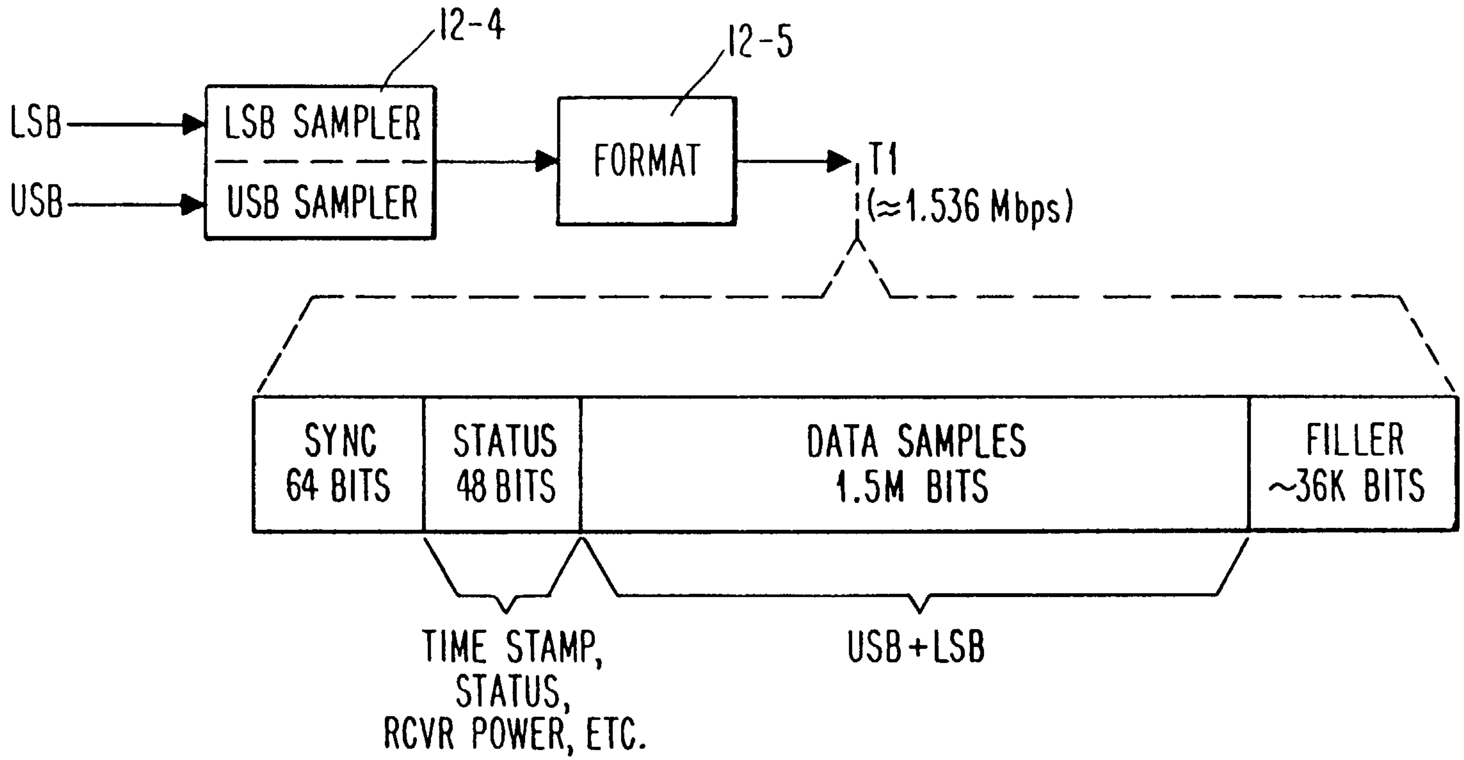
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12-5
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LSB SAMPLER
USB SAMPLER
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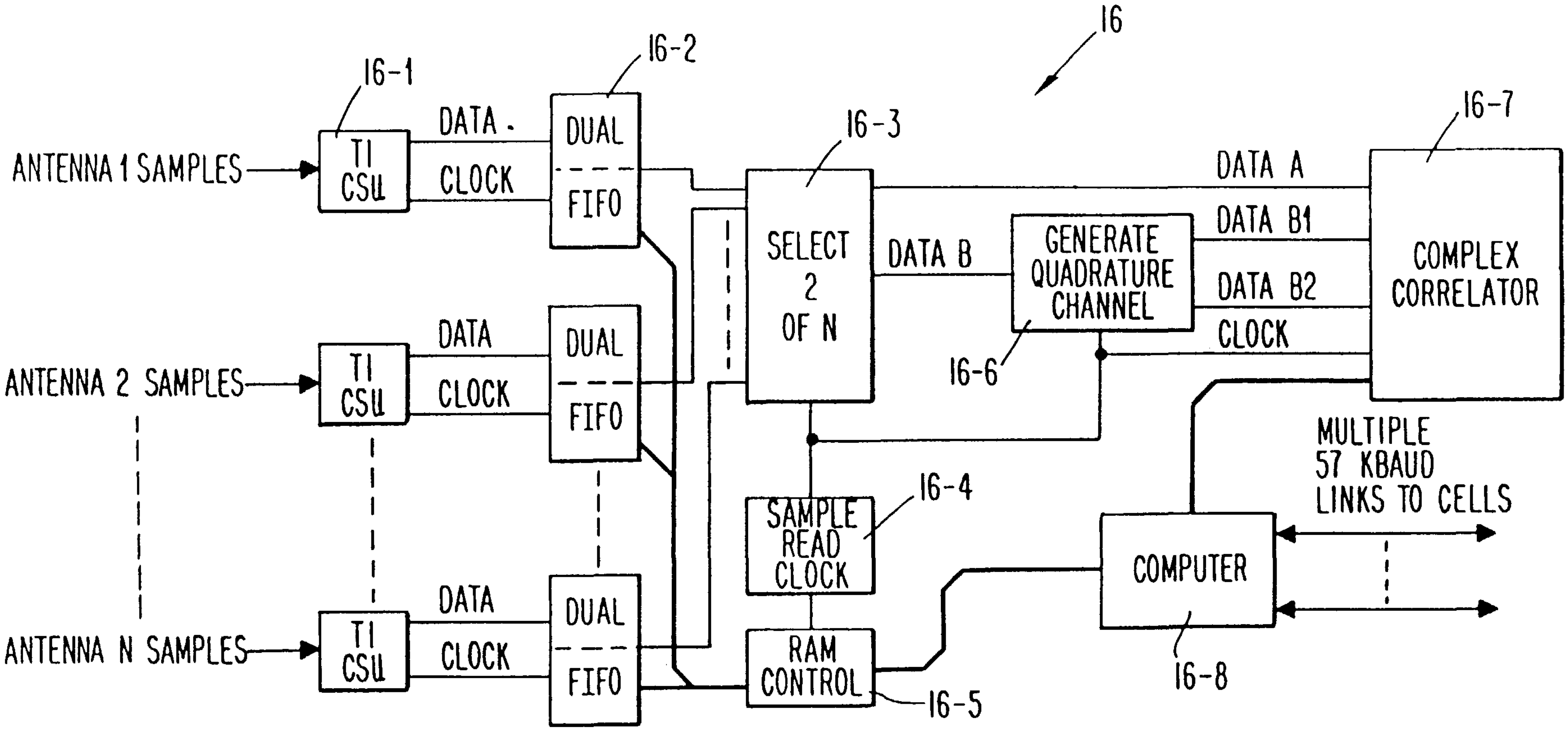
FILLER ~36K BITS
TIME STAMP, STATUS, RCVR POWER, ETC.
USB+LSB

Fig. 5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ANTENNA 1 SAMPLES
ANTENNA 2 SAMPLES
ANTENNA N SAMPLES
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CSU
T1
CSU
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DATA
CLOCK
DATA
CLOCK
16-2
DUAL
FIFO
DUAL
FIFO
DUAL
FIFO
16-3
SELECT
2
OF N
DATA B
16-4
SAMPLE
READ
CLOCK
RAM
CONTROL
16-5
GENERATE
QUADRATURE
CHANNEL
16-6
DATA A
DATA B1
DATA B2
CLOCK
16-7
COMPLEX
CORRELATOR
MULTIPLE
57 KBAUD
LINKS TO CELLS
COMPUTER
16-8

Fig. 6

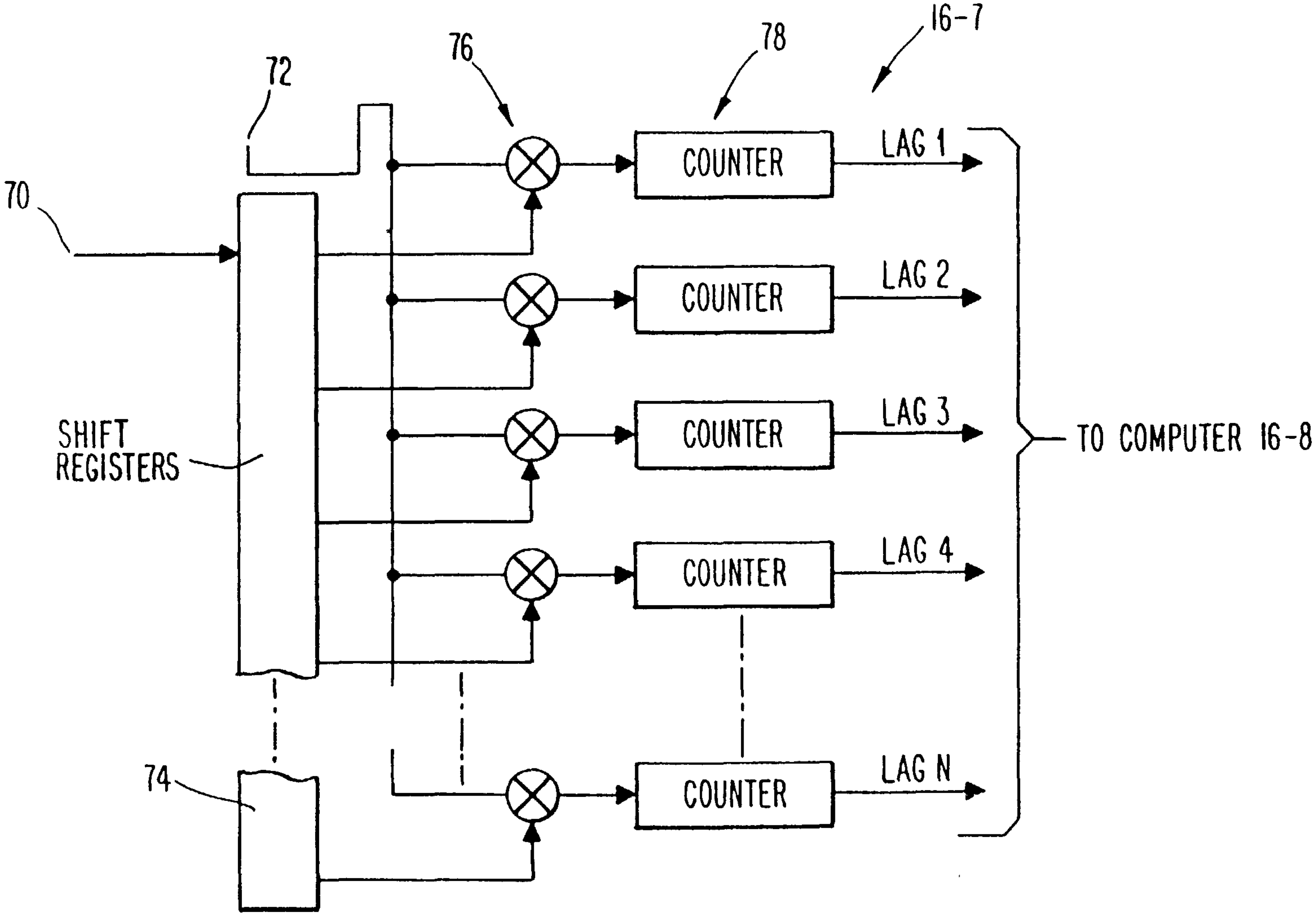

16-7
78
76
72
70
COUNTER
LAG 1
COUNTER
LAG 2
COUNTER
LAG 3
SHIFT
REGISTERS
TO COMPUTER 16-8
COUNTER
LAG 4
74
COUNTER
LAG N

Fig. 6A

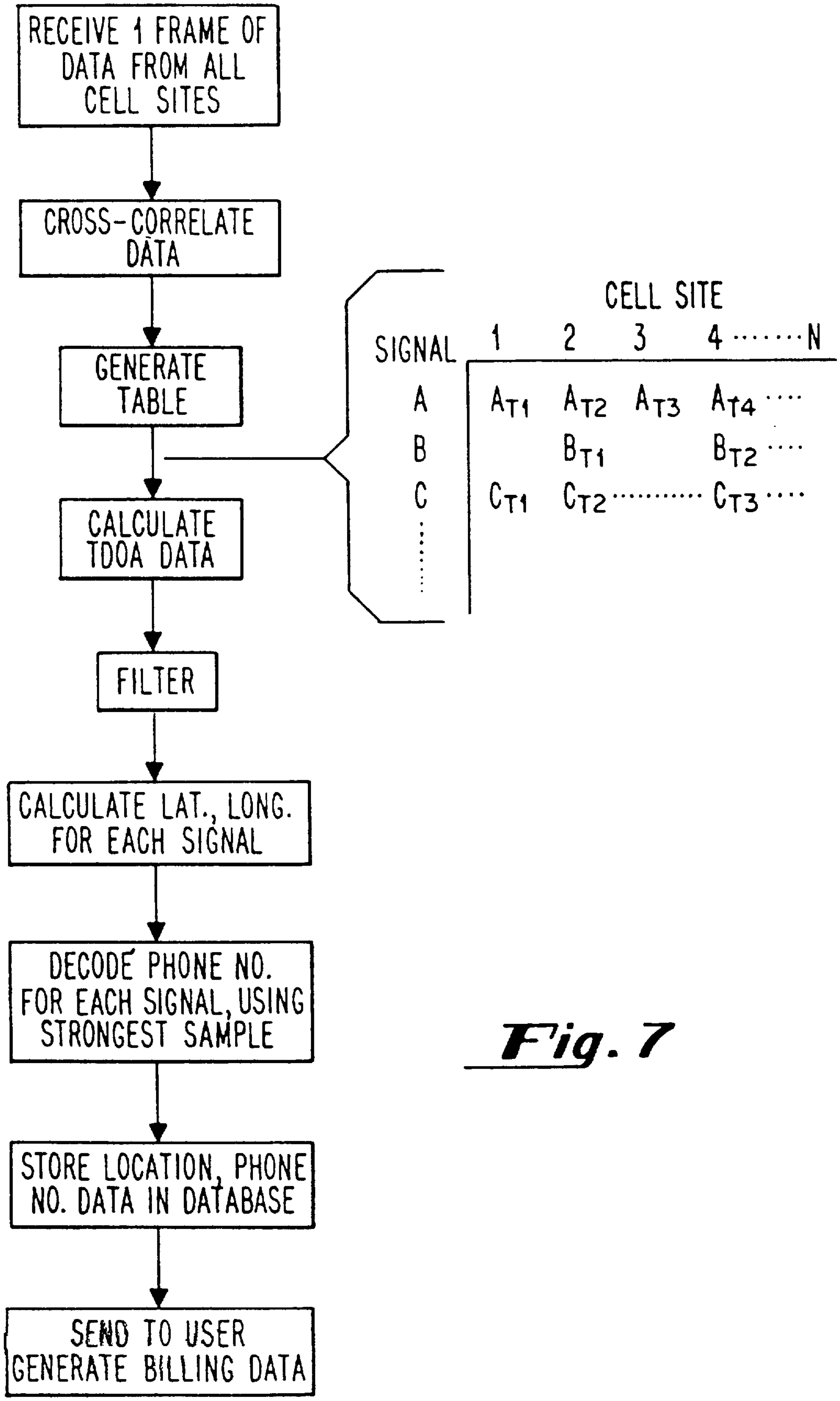

RECEIVE 1 FRAME OF DATA FROM ALL CELL SITES
CROSS-CORRELATE DATA
GENERATE TABLE
CALCULATE TDOA DATA
FILTER
CALCULATE LAT., LONG. FOR EACH SIGNAL
DECODE PHONE NO. FOR EACH SIGNAL, USING STRONGEST SAMPLE
STORE LOCATION, PHONE NO. DATA IN DATABASE
SEND TO USER GENERATE BILLING DATA
CELL SITE
SIGNAL
1 2 3 4 ...... N
A A_{T1} A_{T2} A_{T3} A_{T4} ....
B B_{T1} B_{T2} ....
C C_{T1} C_{T2} .... C_{T3} ....

Fig. 7

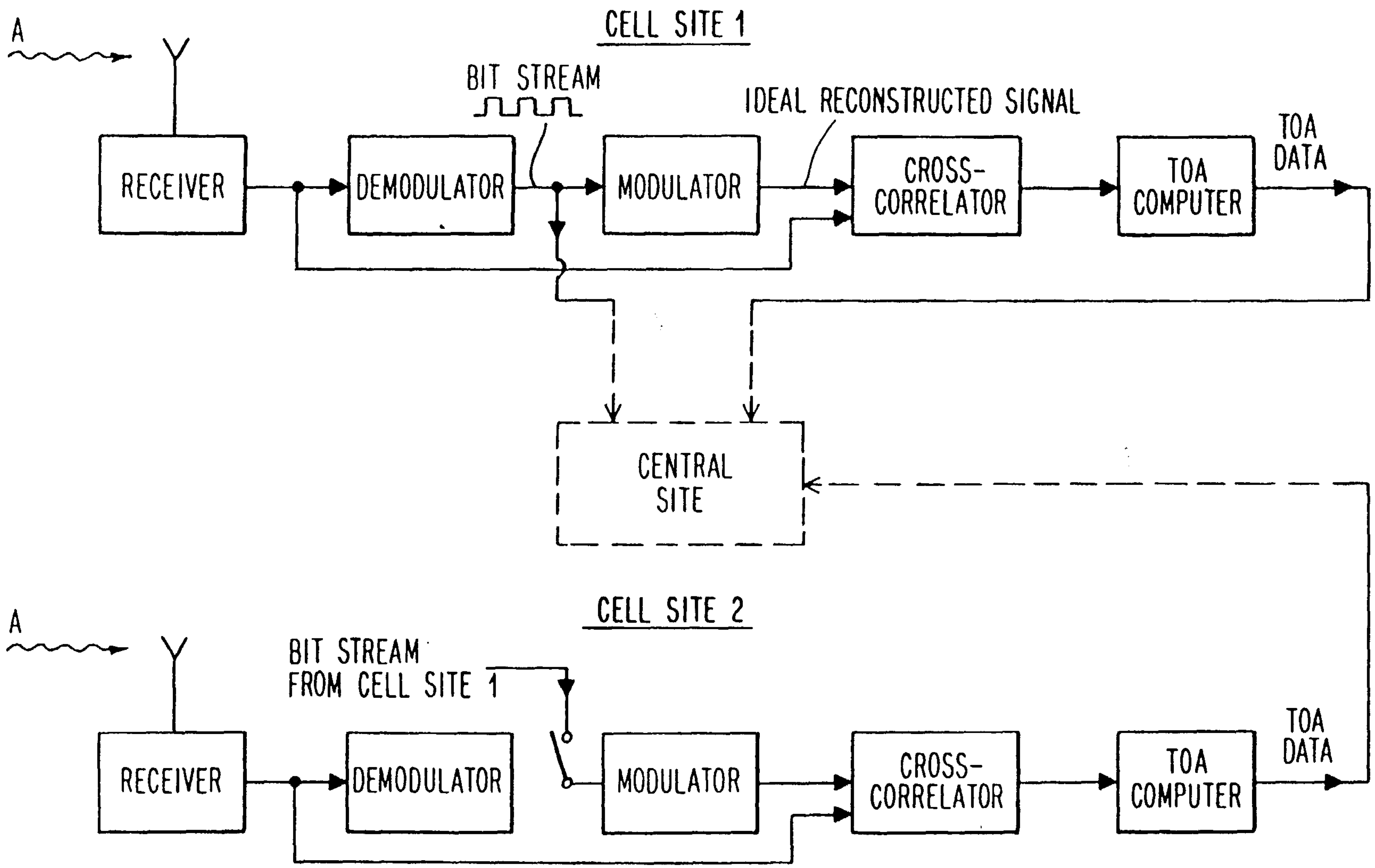

CELL SITE 1
A
BIT STREAM
IDEAL RECONSTRUCTED SIGNAL
RECEIVER
DEMODULATOR
MODULATOR
CROSS-CORRELATOR
TOA COMPUTER
TOA DATA
CENTRAL SITE
CELL SITE 2
A
BIT STREAM FROM CELL SITE 1
RECEIVER
DEMODULATOR
MODULATOR
CROSS-CORRELATOR
TOA COMPUTER
TOA DATA

Fig. 7A

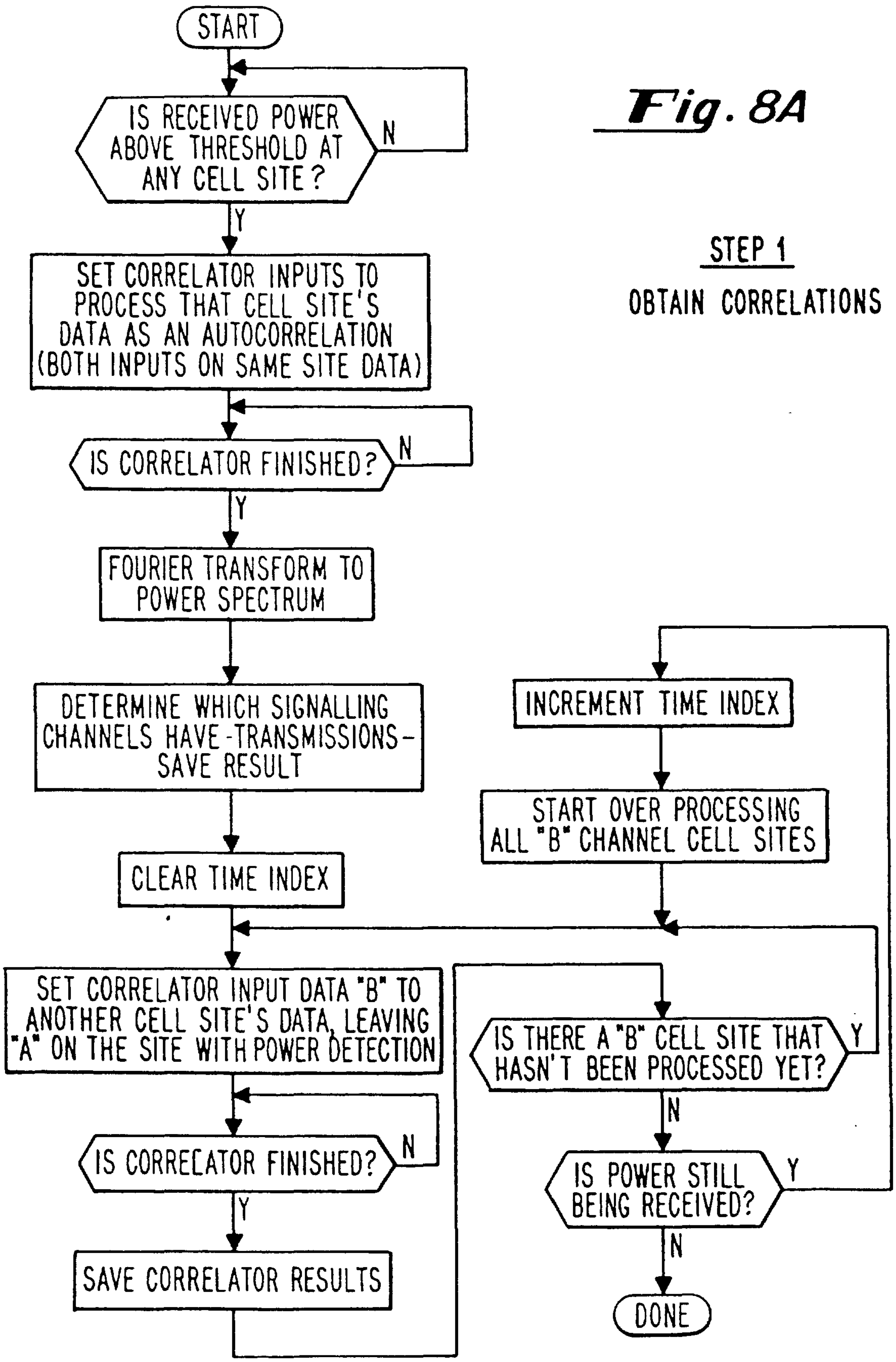


Fig. 8A

STEP 1

OBTAIN CORRELATIONS

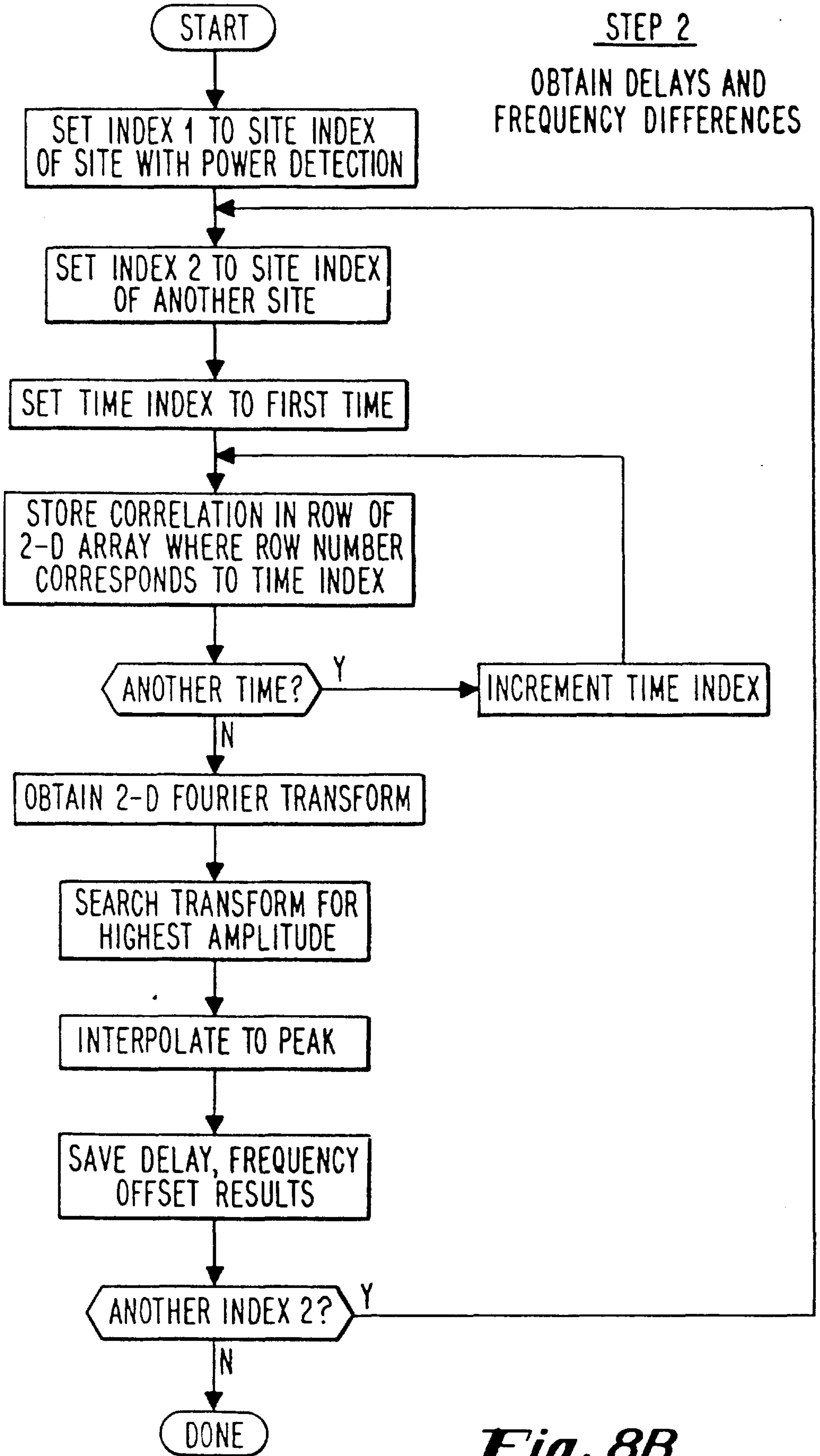

START
STEP 2
OBTAIN DELAYS AND FREQUENCY DIFFERENCES
SET INDEX 1 TO SITE INDEX OF SITE WITH POWER DETECTION
SET INDEX 2 TO SITE INDEX OF ANOTHER SITE
SET TIME INDEX TO FIRST TIME
STORE CORRELATION IN ROW OF 2-D ARRAY WHERE ROW NUMBER CORRESPONDS TO TIME INDEX
ANOTHER TIME?
Y
INCREMENT TIME INDEX
N
OBTAIN 2-D FOURIER TRANSFORM
SEARCH TRANSFORM FOR HIGHEST AMPLITUDE
INTERPOLATE TO PEAK
SAVE DELAY, FREQUENCY OFFSET RESULTS
ANOTHER INDEX 2?
Y
N
DONE

Fig. 8B

Fig. 8C

STEP 3

ESTIMATE LOCATION

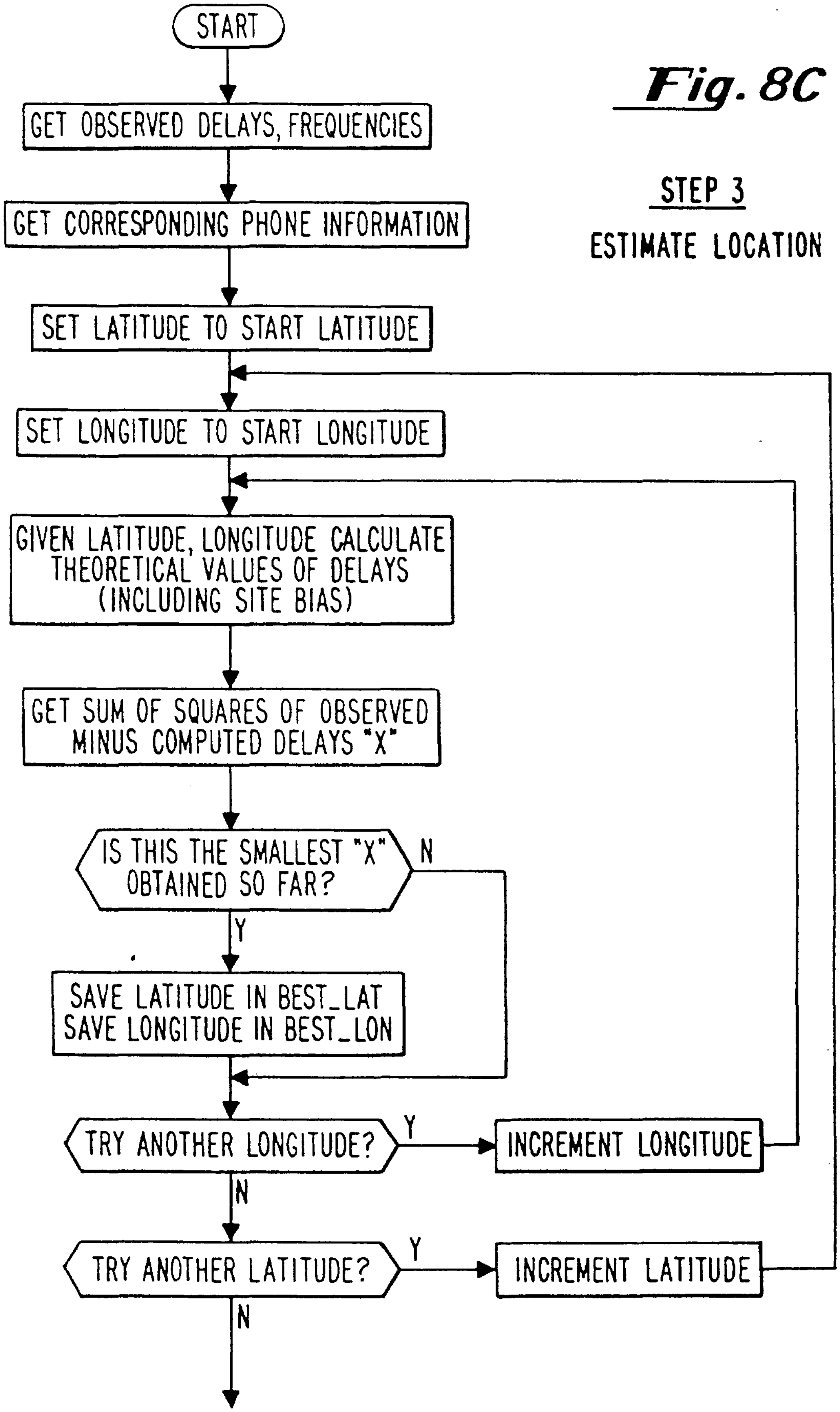
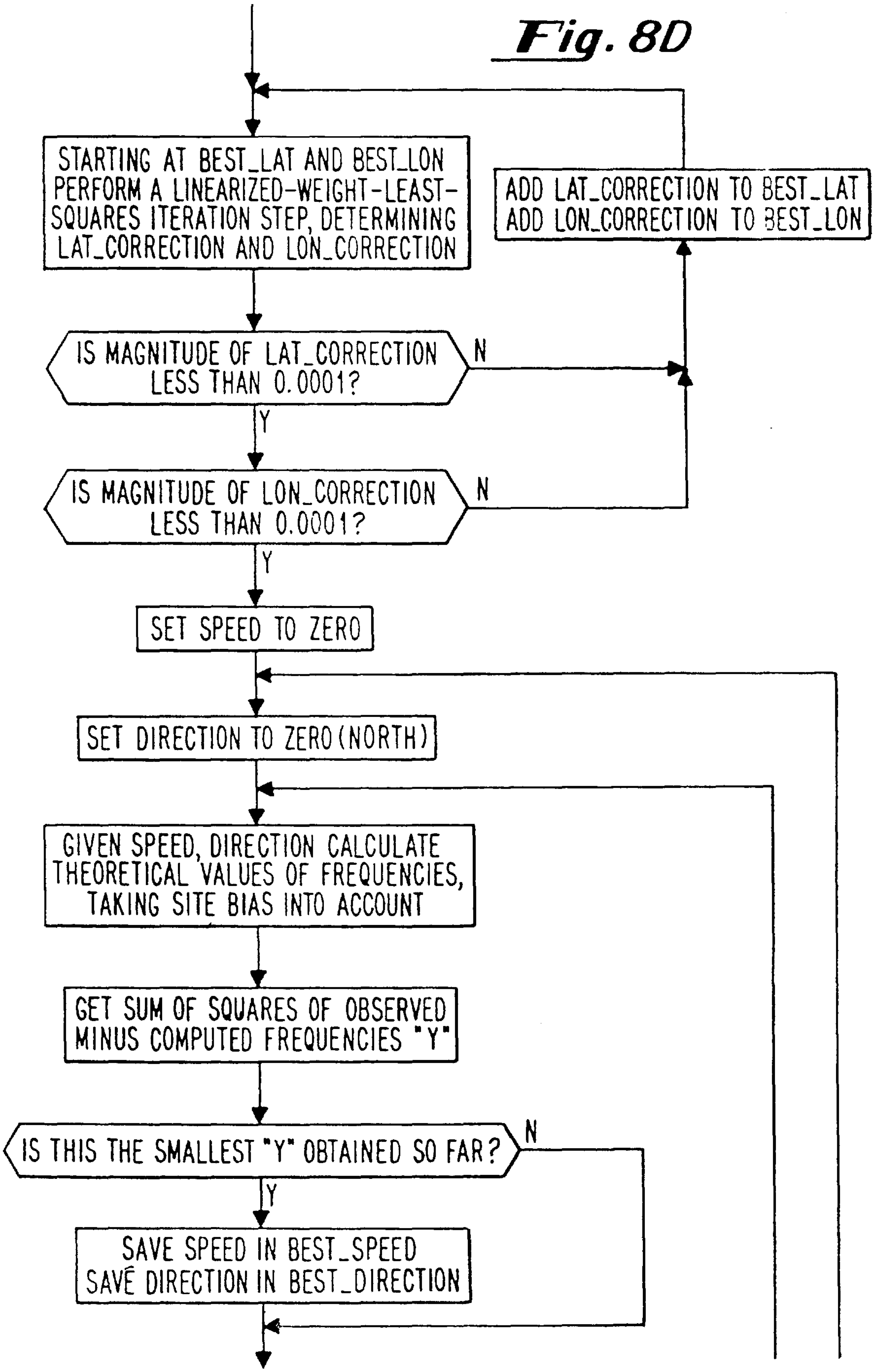


Fig. 8D


STARTING AT BEST_LAT AND BEST_LON PERFORM A LINEARIZED-WEIGHT-LEAST-SQUARES ITERATION STEP, DETERMINING LAT_CORRECTION AND LON_CORRECTION
ADD LAT_CORRECTION TO BEST_LAT ADD LON_CORRECTION TO BEST_LON
IS MAGNITUDE OF LAT_CORRECTION LESS THAN 0.0001?
N
Y
IS MAGNITUDE OF LON_CORRECTION LESS THAN 0.0001?
N
Y
SET SPEED TO ZERO
SET DIRECTION TO ZERO (NORTH)
GIVEN SPEED, DIRECTION CALCULATE THEORETICAL VALUES OF FREQUENCIES, TAKING SITE BIAS INTO ACCOUNT
GET SUM OF SQUARES OF OBSERVED MINUS COMPUTED FREQUENCIES "Y"
IS THIS THE SMALLEST "Y" OBTAINED SO FAR?
N
Y
SAVE SPEED IN BEST_SPEED SAVE DIRECTION IN BEST_DIRECTION

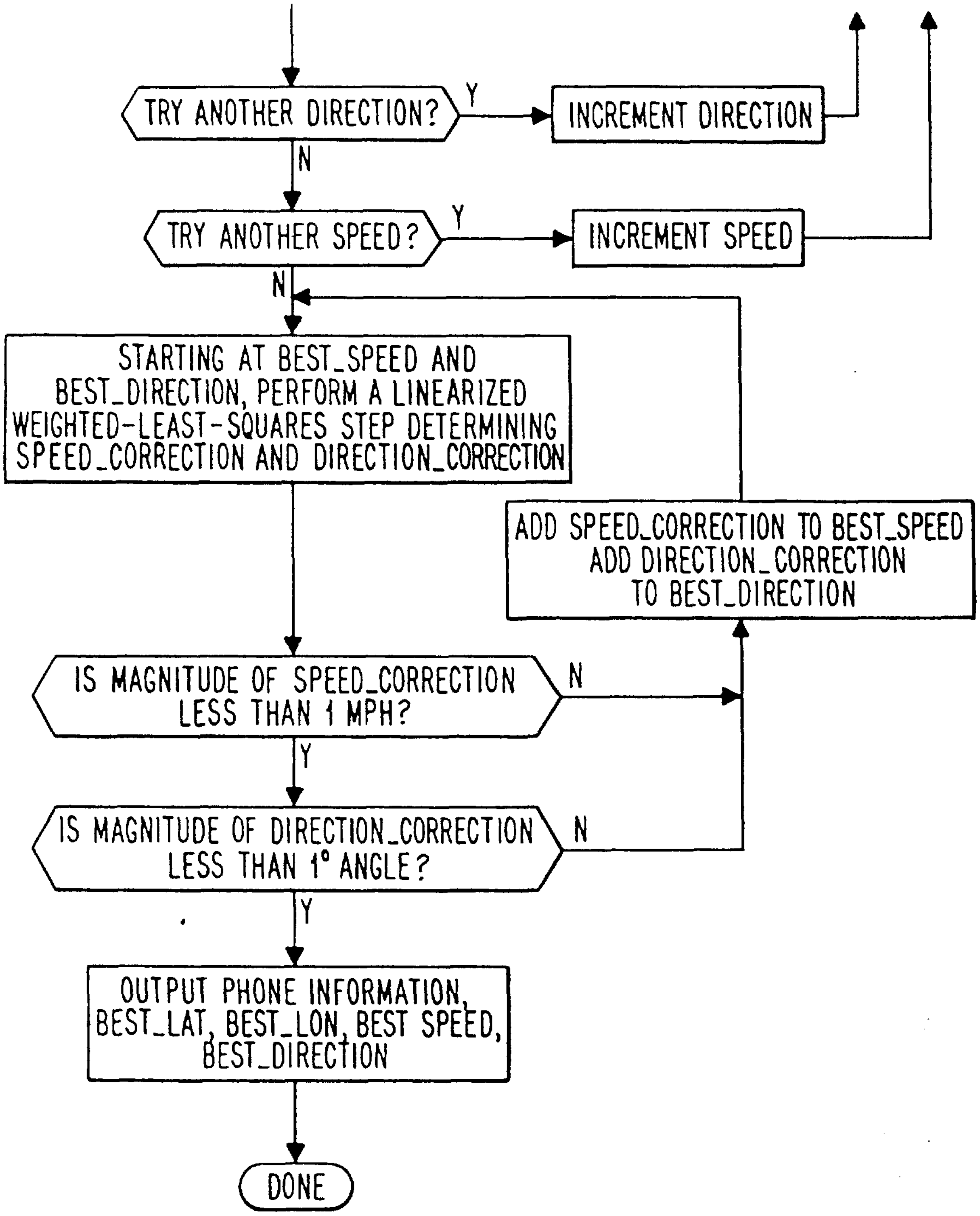

TRY ANOTHER DIRECTION?
Y
INCREMENT DIRECTION
N
TRY ANOTHER SPEED?
Y
INCREMENT SPEED
N
STARTING AT BEST_SPEED AND BEST_DIRECTION, PERFORM A LINEARIZED WEIGHTED-LEAST-SQUARES STEP DETERMINING SPEED_CORRECTION AND DIRECTION_CORRECTION
ADD SPEED_CORRECTION TO BEST_SPEED ADD DIRECTION_CORRECTION TO BEST_DIRECTION
IS MAGNITUDE OF SPEED_CORRECTION LESS THAN 1 MPH?
N
Y
IS MAGNITUDE OF DIRECTION_CORRECTION LESS THAN 1° ANGLE?
N
Y
OUTPUT PHONE INFORMATION, BEST_LAT, BEST_LON, BEST SPEED, BEST_DIRECTION
DONE

Fig. 8E

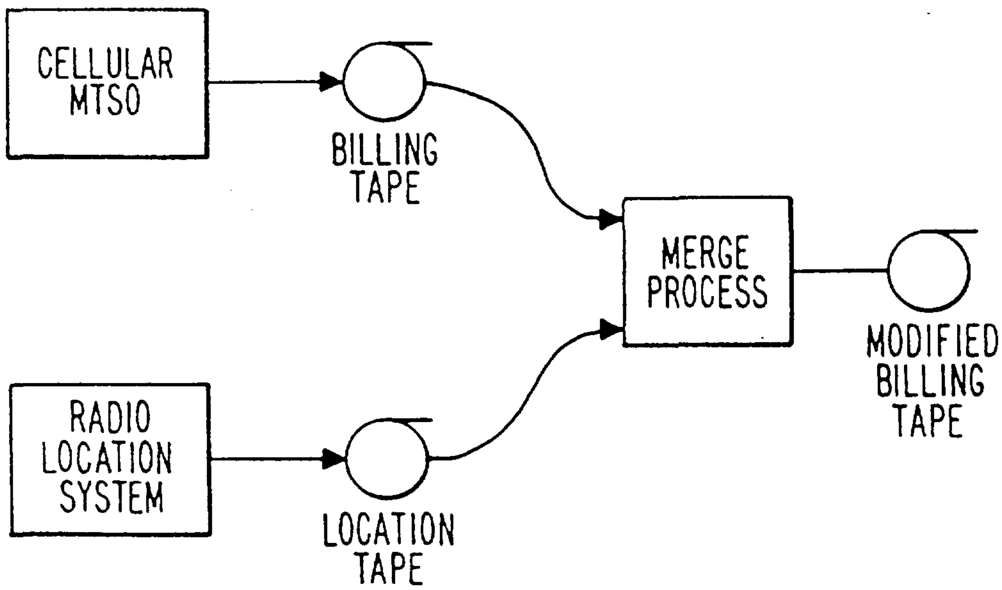

CELLULAR
MTSO
BILLING
TAPE
MERGE
PROCESS
MODIFIED
BILLING
TAPE
RADIO
LOCATION
SYSTEM
LOCATION
TAPE

Fig. 9